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ABSTRACT

A traditional introductory college astronomy course was restructured along constructivist lines to better foster a key component of science literacy: critical thinking about problems in science. The restructured course was lecture-free, problem-centered, and collaborative in structure. The Reflective Judgment Framework was used to better understand how the restructured course fostered critical thinking in science. Qualitative data were collected in the form of student interviews, student coursework, researcher field notes, and student learning journals. The students in the restructured course demonstrated significant diversity in their capacity to apply reflective judgment in the context of science. The course was experienced by students very differently as a function of reflective judgment development. It is recommended that introductory courses be restructured along constructivist lines to better foster reflective judgment. (Contains 27 references.) (Author)

A CONSTRUCTIVIST APPROACH TO REFLECTIVE JUDGMENT & SCIENCE LITERACY IN INTRODUCTORY COLLEGE SCIENCE INSTRUCTION

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Abstract

A traditional introductory college astronomy course was restructured along constructivist lines to better foster a key component of science literacy: critical thinking about problems in science. The restructured course was lecture-free, problem-centered, and collaborative in structure. The Reflective Judgment Framework was used to better understand how the restructured course fostered critical thinking in science. Qualitative data were collected in the form of student interviews, student coursework, researcher fieldnotes, and student learning journals. The students in the restructured course demonstrated significant diversity in the capacity to apply reflective judgment in the context of science. The course was experienced by students very differently as a function of reflective judgment development. It is recommended that introductory courses be restructured along constructivist lines to better foster reflective judgment.

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The Idaho Project NOVA[1] Framework for Educating Science Literacy

> Science has always been a weakness, an area I avoided with vehemence. I remember 8th grade biology when my elementary principal father caught me memorizing the first three words only, of the definitions that were to appear on the final the next day...Me? I was content doing what I needed to receive the grade expected of me. Astronomy has changed a lot of that. I called my mom the other day and told her how much I was learning, how much I understood, all the questions I was left with. She could only muse with a giggle, 'what college has done to my baby'...For the first time in my life I'm excited about science. The most valuable thing I came away with was self-assurance, that maybe I'm not so illiterate, and there is science that I can not only understand but on which I want to expand my knowledge of, no more three-word memorization. (Art/Elementary Education Major, Idaho Project NOVA Introductory Astronomy 103 Course, Learning Journal; 12/12/96)

Effective reform aimed at intellectual development in science education requires a thorough rethinking of the pedagogical framework within which science instruction is carried out. Structuring a science course to foster intellectual development involves much more than deciding what content to cover. This study focuses specifically on efforts to redesign instruction to facilitate an environment in which students can develop a key element of science literacy: the capacity for and disposition toward reflective judgment in the context of science.

Reflective Judgment: A Key Benchmark of Science Literacy

The landmark document *Benchmarks for Science Literacy* (AAAS Project 2061, 1993) set in place specific goals for science literacy, mapping content objectives onto each

[1] Idaho Project NOVA is a NASA-sponsored program designed to promote science literacy in higher education.

grade level from kindergarten through twelfth grade. Development of critical thinking in science is suggested by *Benchmarks* as a primary component of science literacy throughout schooling. Project 2061 suggests that by grade two students should "ask 'how do you know?' in appropriate situations and attempt reasonable answers..."(AAAS, 1993, p. 298). It is suggested that by grade 12 students be able to "insist that critical assumptions behind any line of reasoning be made explicit so that the validity of the position being taken may be judged," and, "suggest alternative ways of explaining data and criticize arguments in which data, explanations, or conclusions are represented as the only ones worth consideration" (AAAS, 1993, p. 300).

Research on the reflective reasoning capability of college students suggests that most fail to meet Project 2061's grade 12 goals (King & Kitchener, 1994, p.168). In fact, Project 2061's benchmark for grade 12 prescribes a view of scientific knowledge that is at odds with views held by the broad majority of students entering college. It is left up to undergraduate education to address this deficiency in the capacity for reflective judgment in science in order to foster science literacy. College educators must first define what is meant by "reflective judgement," and then take steps to restructure curricula that support its practice and growth.

The Reflective Judgment Framework

The Reflective Judgment Framework (RJF) is a powerful tool for assessing and understanding the disposition toward, and the use of, reflective judgment. The RJF, developed over a ten year period of study involving over 2000 subjects, is a developmental model describing the changing patterns of reasoning over a person's life-span (King & Kitchener, 1994). Reasoning level is evaluated by analyzing recorded interviews in which individuals are engaged in thinking about ill-defined problems for which evidence exists to support two or more different solutions or options.

Analysis of over 2000 intensive interviews of college students suggested a three-level developmental model based on the way personal view of knowledge and concept of justification changed over time (see Table 1.) *Pre-Reflective*, *Quasi-Reflective*, and *Reflective* levels of reasoning, characterized by distinct views of knowledge and justification, provide a powerful tool by which the developmental nature of reflective thinking may be understood.

Table 1

Overview of Reflective Judgment Framework (Adapted from King & Kitchener, 1994, p. 44-74)

Phases	View of Knowledge	Concept of Justification
Pre-Reflective	Absolutely certain or temporarily uncertain	Authority based (known) Opinion based (unknown)
Quasi-Reflective	Always uncertain	Contextual, observer-dependent justification
Reflective	Outcome of process of evaluation. Represented as the most complete, plausible model based on the current evidence.	Weight of the evidence, weakness of alternatives, value of interpretations

Reflective Knowing

Reflective knowing is a process of inquiry. The reflective view of knowledge can be contrasted with knowing as "hearing from authority" (pre-reflective) and knowing as "having your own opinion" (quasi-reflective). Reflective judgment is the capacity for constructing one's own picture of reality based on a variety of evidence, including personal/social experience, the critically evaluated ideas and opinions of expert others, experimentation, and so on.

The developmental stages of reflective judgment represent a way of understanding how individuals think about ill-defined problems. To speak of individuals as though they are 'in' a certain reflective judgment stage is, however, an oversimplification. Persons exhibit a spectrum of different thinking levels which are domain specific, often approaching problems differently depending on context and environment (King & Kitchener, 1994, p.242-243). It is helpful to differentiate between *optimal level* of RJ, defined as "the upper limit of the person's general information processing capacity," and *functional level* of reflective judgment. Functional level refers to the way a person applies the range of levels of reflective thought in various settings and to various problem types (Kitchener & Fisher, 1990, p.54). Developmental change in RJ may be viewed as first an upward shift of a person's optimal level of reflective judgment, followed by a functional integration of the higher optimal level into other domains and environments over time.

Fostering Reflective Judgment in College

Studies involving incoming university freshmen suggest an average optimal reflective judgment capacity of about stage 3.5 (SD $\cong$ .5), on the boundary between pre-reflective and quasi-reflective functioning (see King and Kitchener, 1994, p.165). Reassessment of students as college seniors suggests an average gain of approximately onehalf stage. Advanced graduate students have been studied, with an average result of stage 5.8.

These findings are extremely important in a two-fold sense for those involved in reforming college instruction. First, the findings suggest that most incoming college freshmen are functionally pre- or quasi-reflective thinkers, and struggle to engage in the levels of reasoning required to analyze ill-defined problems within the academic disciplines. Instruction must be appropriate for stage 3-4 reasoners, stimulating reflective thought within the range of viability for practice and growth.

Second, the findings suggest that the bulk of incoming students demonstrate a functional level that is distributed through two very different views of knowledge. The shift in thinking between pre- and quasi-reflective reasoning is accompanied by an abrupt change in epistemological assumptions, from an authority-based to a contextually-based view of knowledge. The tension between the fixed, authority-based view of knowledge and the uncertain, contextually-based view of knowledge is therefore at a heightened level during the college years. Instructional environments which attempt to foster reflective judgment are predictably stressful, and often emotional for students and teachers alike (Kroll, 1992). Restructuring therefore ought to account for both the cognitive and affective nature of the developmental task of reflective judgment, treating both as equally vital to the promotion of intellectual growth.

Idaho NOVA Restructured Astronomy Course

Idaho NOVA restructured its introductory astronomy course so that, rather than learning *about* astronomy, students actively reconstructed astronomy themselves. By placing the focus on the process of inquiry and answering the question "how do we know?" a curricular environment for reflective thinking was established.

Such an approach fits many of the suppositions of constructivist pedagogy. Constructivism challenges many traditionally held notions of science teaching. Traditional approaches to science teaching view *transmission*, rather than *facilitation*, as the primary goal of instruction. The transmission model of instruction emphasizes the role of teacher explanation, sees students as passive receptors of information, and designs instruction so as to best broadcast knowledge through the "conduits" of lecture, demonstration, and structured lab activities. The acceptance of transmission pedagogy in introductory science teaching is seen in the prevalence of non-collaborative, large-lecture instruction, on-going reduction in the demand for reflective judgment, and the failure to foster authentic inquiry (Tobin & Espinet, 1989; Tobin, Espinet, Byrd, & Adams, 1988; Tobin & Gallagher, 1987a; Tobin & Gallagher, 1987b).

In general, the constructivist view of knowledge development emphasizes socially and personally negotiated meaning, placing the student-teacher community at the center of learning (Tobin, Tippins, & Gallard, 1994). Constructivist learning is viewed as a pursuit of co-discovery through authentic inquiry, in which facilitation of knowledge development and negotiation of meaning is the primary goal of curriculum and instruction.

The task undertaken by Idaho Project NOVA was to restructure its Introductory Astronomy course, popular with non-science majors and elementary educators, to better fit constructivist ideals. This paper seeks first to describe some of the details of the course restructuring. A qualitative analysis and interpretation of the course is then presented which serve to contrast the ways different students experienced, practiced and developed reflective judgment in the restructured course.

Methods

This is a naturalistic case study, providing a focussed and in-depth view of a single case or instance of the topic of inquiry. The *naturalistic* case study method is a dynamic approach well suited to theory grounding and extension (Lee, 1989). A case study researcher interacts (as the instrument) fluidly between observation and theory, allowing the former to extend and modify the latter. In this study, the case study researcher was also an assistant course instructor, providing a unique internal perspective.

This case study seeks an inside view of student experience from many different viewpoints, described in detail below. This "triangulation" of data sources yields a variety of filters, through which experiences are observed, described and analyzed. A rich collage of "snapshots," taken through a myriad of lenses, constitutes the basis for theory extension and development.

Data Generation

The data sources generated included student reports and reflective essays, video tapes, audio tapes, formal and informal interviews, researcher self-reporting, third-party field observations, and course evaluations.

Structured on-line interviews.

Forty of 60 enrolled students responded to three "on-line" interviews, administered in campus computer labs using the Internet. The three interviews were distributed to obtain data at the start, middle, and end of the course. The interview questions elicited specific student feedback about the way the course was structured with regard to fostering reflective judgment. Each student participated in the "interviews" by filling out forms found on the course Internet site. Each student's input, electronically compiled by a network server, was systematically filed by student name and question type.

Reflective learning journals.

Each student maintained a reflective learning journal, making entries each class period. Most entries are open-ended, but occasionally the researcher requested feedback about specific issues. The learning journals enhanced observations of both student use of, and disposition toward, reflective judgment.

Final exam responses.

Sixty students completed a final course exam designed to provide the opportunity to engage in reflective judgment in the context of an issue in astronomy. The content was designed to assess each student's ability to a) describe the observations that are explained by a given model, b) to point out weaknesses in the model, and c) to explain why scientific models are changed and sometimes discarded.

Student reflective essays.

Ungraded reflective essays were completed by 45 students under the topic "Summarize your learning in this course." Responses ranged in length from 1-3 typed pages.

Informal interviews.

Periodically, the researcher conducted informal interviews. The researcher post-recorded approximately 20 interviews of this type.

Participant observations.

Data sources generated through participant observations were recorded in the form of field notes, video and audio recording. The researcher compiled hand-written on-site observations for 48 class sessions of 50 minutes duration each and 52 lab sessions of two hours duration each, over a thirteen week period from August to December, 1996.

Data Analysis

The naturalistic case study model calls for a dynamic approach to analysis for developing, modifying, and grounding theory. Data analysis intermingles with data collection, providing dynamic feedback, which drove both on-going analysis and the evolution of the research context itself.

At the completion of the study, the reduced data consisted of 15 complete student records, field notes, and audio recordings of group interaction. Respondent anonymity was enforced at this level of the study by re-coding entries by two-digit initials. The database was then re-analyzed with respect to the Reflective Judgement Framework.

Interpretation and Theory Modification: Researcher as Instrument

> When the researcher gets right to it, it is an awesome, even frightening responsibility to bow to the fact that 'self-as-instrument' inevitably means one must create on-going meaning out of the evolving and evolved data, since raw data alone have little value. (Ely, 1991, p.86)

Qualitative research seeks to extend and modify theory through an ongoing process of analysis and interpretation by the researcher. In critiquing this study, it is important to regard the researcher as the primary instrument by which data and observations are collected, organized and interpreted. The teacher/researcher in a case study is deeply embedded in the fabric of the research context, lending individual texture to the conclusions drawn. This powerful aspect of qualitative inquiry leads to theory modification which is both subjective and creative.

Results Of Inquiry

Description of Course Restructuring

> After writing the last essay I think I understand what purpose of this sort of hazy wandering through astronomy was. If no answers were really given to us, just facts, all of the construction or synthesis of these facts were up to us to put together. This is a lot more work, because we are asked to go through the mental steps that so many astronomers have gone through before. (Student Reflection, 12/12/96)

The Introductory Astronomy 103 course was restructured so as to turn the traditional teaching of the topic of cosmology on its head. For example, in conventional lecture courses the development of the modern view of the solar system is presented in a linear fashion by the instructor. Students are then tested on facts. The assumptions are that teaching is transmission, that thinking is memorizing, and that knowledge is fixed and known, assumptions which hardly support development of reflective judgment.

The assumptions guiding course restructuring were that teaching is facilitation, thinking is evaluating, and knowledge is dynamic and growing. Rather than attending to lectures, students were instead asked to "discover" the heliocentric model for themselves by retracing the steps taken in evaluating and justifying successive models, beginning from scratch with their own personal, self-constructed cosmology. During this process of discovery, most of the "facts" about the solar system that are commonly assigned as reading or outlined in test study guides are learned in the natural course of inquiry.

Course activities were designed to provide students with observations such as retrograde motion of Mars and the maximum elongation of Venus and Mercury, which are easily observable to the naked eye, yet cannot be explained with the primitive geocentric model of the solar system. Through group discussion and guided facilitation, students evaluated and reconstructed improved models, using Ptolemaic devices such as epicycles. As each new model was built, new observations were introduced which served to call the model into question. Galileo's telescopic observation of the phases of Venus finally calls into question the geocentric model, and students "discover" that a heliocentric model is more fitting. More observations are introduced, suggesting elliptical orbits, the size and distance scale of the solar system, the existence of "new" planets like Neptune, and so on, until a reasonably sophisticated solar system cosmology is built.

Levels of Student Reflective Judgment

Evaluating and modifying scientific models places heavy demands on reflective judgment. The view of knowledge at work in evaluating and modifying models is that of a dynamic, changing reality which is understood indirectly and through a variety of different lenses. Scientific models display varying degrees of "rightness" depending on their usefulness in context. This suggests a non-authoritarian concept of justification, in which many different models of the same phenomenon are justified on different grounds or used for different purposes. Tasks involving evaluation and modification of models invite a reflective view of knowledge as a "process of construction."

The students in the restructured course applied to the problem of constructing cosmology varying levels of reflective judgment. Consistent with King and Kitchener's studies of college students, a wide variation in reflective judgment capacity was observed, ranging from clearly pre-reflective stage 3 reasoning to highly reflective reasoning indicative of stage 7 (see Tables 2 & 3.)

Table 2

Observed Concepts of Knowledge

Pre-Reflective	Quasi-Reflective	Reflective
To prove something as *a fact means that it is true. The proven fact is seen by all.* If one person sees that proven fact to be different then the fact is not true.	I think the main idea of today was that a lot of things we perceive to be fact are just a matter of perception... *proof is in a way impossible to find because what one person may see as absolute proof may be false to another.*	This is not to say that we might show our current 'knowledge' of the solar system to be false, but rather *to question how much our methods of fact discovery and proof might actually effect the facts we determine to be true*. The phases of Venus helped disprove the Ptolemaic model . . .the only adequate way to explain those phases is through the heliocentric model.
[Knowledge is viewed as fixed and external to the knower. Proof is fixed and independent of the observer or context.]	[Knowledge is viewed as contextual and entirely dependent on the observer. Fixed proof in the pre-reflective sense is denied.]	[Knowledge is viewed as the product of a contextual process of evaluation and modification. Proof consists of predictive ability within context.]

Note: Observations from Student Learning Journals, various dates; [ ]=researcher note, *italics* added for emphasis

Table 3

Observed Concepts Of Justification

Pre-reflective	Quasi-reflective	Reflective
In order for the current model to change *there has to be something to prove all these theories wrong. In order to do that we have to wait to see what is going to happen*...All the models in the world could explain what has happened up until now but the future could only be explained by one thing: TIME. I think the only way we can see what will happen in the universe is by waiting to see if any of our theories is correct	So far it looks like we have lots of evidence that the universe is still expanding. [Do you think it will keep expanding?] *Whether it will continue to expand is a question with no answers.* *What does it mean to prove something? My terms or yours?*	First of all a model is good as long as it can logically explain everything it deals with. So if we should later on find through research that it contradicts the models we have now we have to find new models which can explain these controversies and solve them. It is important to match models to observations or the models are not very good. The heliocentric model allows the accurate prediction and positioning of planets without any complications like epicycles.
[Student sees the role of theory as defining certainty, and justification except by direct observation is disallowed.]	[Student sees uncertainty theory, but is unable to use evidence to support or refute a point of view.]	[Students see the role of theory as tentative in nature and explanatory in purpose.]

Note: Observations from Student Final Examinations, 12/12/97; [ ] = researcher comment, *italics* added for emphasis)

Interpreting Experiences in the Constructivist Course

"We discuss this stuff so much more—it's like it's part of our lives."
(Informal Interview, 9/19/96)

A learning environment built around group interaction, discussion, and reflective thinking fundamentally alters the role of the instructor, decentralizing the basis of authority in the classroom. "Downward mobility" on the part of the instructor is initially uncomfortable for both teacher and students. Heightened student awareness of learning and an increased level of "student voice" in the classroom is at once troubling and liberating. The constructivist course violated many students' expectation for what a science course should be. Students reacted both positively and negatively, depending again, to a great extent, on their held view of scientific knowledge and reflective judgment developmental stage.

Student expectations.

Students expected non-interactive, lecture instruction from their science courses (On-line interviews 9/19/96):

> Biology was day after day of straight lecture. We had a lot of information given to us to memorize. We really didn't have an opportunity to apply any of the knowledge so I forgot it the minute the test was over. Geology was much the same way as biology.

> With larger groups it is hard to inspire open discussion on a regular basis, which I assume this class wanted to happen and yet I think that it is just a matter of convention in which most students are used to just sitting through a class with a large number of students in a large lecture hall.

For instructors interested in fostering reflective judgment, these are troubling characterizations. Students see themselves as trained in a system of learning that is lacking in collaboration and use of higher level reflective reasoning.

Decentralizing authority.

Some students experienced the decentralization of authority in the course as a "breath of fresh air" (On-line interview, 9/19/96). Many were pleasantly surprised that science is based on debate and evaluation, and involves inherent uncertainty:

> I've begun to see astronomy as much less of an exact science, which for someone like me, an art major, finds pretty exciting. I detest the idea of everything being concrete and explained in scientific manners. I appreciate the breathing room that astronomy allows for theory and understanding based solely on observation. (Student Reflection, 12/12/96)
>
> The only other time I get to think this way is in my English class. (On-line interview, 12/6/96)

Many students, however, struggled with the course structure. Although these students generally displayed a positive affect toward the restructured class environment, they tended to experience and mask (to varying degrees) stress and frustration. Some students viewed themselves (and others) as "programmed" to learn a certain way, "needing" more structure and "real answers."

> ...at least for me, I need the "cookbook" type of learning. I think the reason I feel this way is because I was always taught with the easy to follow instructions, so it was difficult for me to get used to this new method... (On-line interview, 12/12/96)

Other students viewed the teachers as "obstructionists," or "lazy," unwilling to teach properly:

> ...as I have said before we never get any answers and it is very frustrating. We can't really look in the book to find answers because we don't follow the book. We have no notes to look off of and there is no way to get a straight answer out of either of the teachers. (On-line interview, 12/12/96)

Obviously, there was a wide variation between different ways the course was perceived (see Table 4.) This can again be interpreted in terms of the common theme of how students view science knowledge and learning.

Fostering Development of Reflective Judgment

Negative student disposition toward the restructured course was a cause for some concern. Yet, within the Piagetian (and other) developmental frameworks the stress expressed by students can be understood as indicative of cognitive disequilibrium. The Piagetian framework views cognitive change as driven by a process of equilibration in which the person's cognitive structure reorients in response to novel environmental conditions. The challenge of teaching is to design instruction that fosters an appropriate level of disequilibrium, while also providing adequate cognitive supports.

Social Complexity in Teaching Reflective Judgment

Traditional, non-interactive, lecture-based classrooms tend toward a simple social order in which the teacher centrally holds authority for knowledge and knowing. The linearity of the learning hierarchy in traditional instruction has definite consequences in what is learned and what types of thinking students do.

On the other hand, collaborative, inquiry-based classrooms tend toward a richer, more complex social structure in which authority for knowledge is shared and collectively expressed by the learning community. Like the linearity of traditional class structure, the interconnectedness of learning inherent in the way the NOVA astronomy course was restructured had definite consequences for what was learned and what type of thinking was done. While the restructured course fostered practice of higher levels of reflective judgment, the complexity of the social environment created unique challenges for both students and teachers alike. It is the view of the researcher that overcoming such challenges is in itself a rich learning experience for all involved.

Table 4

Student Course Evaluations

Pre-reflective: Knowledge Is Transmitted	Reflective: Knowledge Is Constructed
"I think in a lot of ways the instructions given are really vague and that kind of frustrates me because I like to know exactly what I have to do and then I like to do it."	"I have enjoyed thinking for myself rather than being lectured at and have enjoyed researching methods of finding what I would normally have found in a book.
"Since there is not any real structure to the class we are pretty much always on our own, especially since you can never get a real answer out of the instructors."	"Thinking for yourself and making up your own mind on whether something is true or not is a good thing which makes this class enjoyable."
"I do like to learn on my own some but to never get any real answers is really annoying... I think the class should be broken down into partial on your own learning and some real lecture."	"I like the fact that I leave the class with questions and then try to figure them out in class. It makes class worth coming to. As well I feel a little confused at times but just enough to make me anticipate the learning, I don't ever feel totally lost. I appreciate that you give us enough time to discover things on our own rather than spoon feeding us."
"I don't feel there was much work or instruction done on the teacher's part, except with coming up with the worksheets, maybe?	
"I don't like to teach myself completely and then be tested on what the professor wants. There is no way of telling what the instructor is looking for because he never gives any guidance."	"I love how you allow us to think about issues and you do not force any definite incorrect/correct answers on us, rather you try to lead us in the direction of correctness"
	"...I have a fixed idea in my head about what I think is right and I am constantly comparing the comments of others and the data presented in class with ideas and weighing whether I think those points are enough to change what I think. If they are I modify my stance and *that is when I have learned something*. I often disregard others opinions in a selective process where I reject what I do not think are valid. *I think this is also learning* as I can recognize a poor argument compared to a good argument."

Discussion

Summary Observations

The NOVA restructured astronomy course was an exercise in radically shifting an authority-based classroom to a collaboratively-based learning community. Students perceived the course very differently as a function of reflective judgment disposition and capacity. One way to understand these differences is to consider student's views of science knowledge and knowing. College students display a wide range of reflective functioning when applied to science. The "deeply diverse" nature of student thinking during the college years creates unique challenges for instructors interested in fostering reflective judgment in their courses, and for the students who take such courses.

Pre-reflective level.

Traditional instruction is typically viewed positively by pre-reflective functioning students, for whom the authority-based view of knowledge and knowing is unchallenged by what is perceived as an authority-based course environment. Whether students develop reflective judgment skills in traditional environments is questionable.

On the other hand, the restructured, lecture-free collaborative course was initially viewed negatively by pre-reflective students. It was evident in the experience described in this study that the decentralization of cognitive authority fostered disequilibrium for pre-reflective students, which, while uncomfortable, in some cases led to positive resolution and awareness of growth:

> This class has been very interesting yet at times it is also very frustrating. I sometimes feel as if I am going around in circles not really knowing which way is up. This past week has been a little better. We have gotten closer on in class work and I feel a little better about it. I have not been bored! I think I learned a great deal of information that will stick with me for a longer period.

> This has given me great opportunities and opened many new doors. No other 'lecture' classes do that. Overall I was frustrated a lot, maybe with my abilities to sit myself down and learn on my own but I did learn and I had a lot of fun doing it. At first, I thought it [the course] was terrible. Over time yes, I enjoyed class and I like learning from my group. It is nice when you do not have to go to a class and just sit and write like crazy for fifty minutes. This class always flew by. Maybe I have become a little more patient, or impatient, because I want everyone to understand my idea and when he or she doesn't, I have to live with it. Maybe [I'm becoming] just a little more open minded to new ideas or different ideas. (Student Learning Journal, 10/6/96)

The restructured course was effective at fostering growth in reflective judgment for pre-reflective functioning science students. The activities, while at times stressful, were well supported by rich peer interaction and modeling. The instructors, who tended to communicate at a reflective level, were somewhat less effective at mentoring pre-reflective functioning students. Some students were left with the impression that the teachers didn't teach very much and that the learning was unnecessarily difficult.

Quasi-reflective level.

For students functioning at the quasi-reflective (stage 4-5) level, traditional science instruction is often viewed as unchallenging or lacking in context The restructured course was seen as opening up a new perspective of science and of learning:

> It was interesting to see that most people could not think of a way to calculate these things. It wasn't that they were not intelligent they just never stop to think about how things work or how we know they work, just like myself. In a sense we are a generation of trust, never question. We believe everything our books tell us and never stop to question them. *I think the reason I have never done well in science is that I have never worked out the information that was spoon-fed to me. Therefore none of it really made sense in the past.* (Student Reflective Essay, 12/10/96)

The restructured course supported growth for students functioning in the quasi-reflective stages, encouraging integration of reflective judgment into what was typically a novel domain, science. The model building tasks were appropriate given the zone of proximal development associated with stages 4-5. Collaborative support was available both from teachers and from those students functioning reflectively with the activities. Some students, as indicated by the reflection above, reported that astronomy was the first science course they have ever enjoyed or felt successful in.

Reflective level.

Surprisingly, traditional instruction was viewed *positively* by students functioning at a highly reflective judgment (stage 6-7) level, while the restructured course was often viewed negatively by such students. On the surface, the expressed concerns seem to mirror those of pre-reflective students. However, closer examination of student responses suggests that the perception of what is happened in the course was actually quite different:

> I hate the fact the lecture approaches concepts, gets everyone's opinion and prediction on those concepts, but then never actually discusses the foundations of those concepts. The belief that, "No one can be wrong in this course," is a poor belief to spread to college students. To actually believe that we can go on in other courses with the belief that "We can't be wrong," is a poor teaching technique. In the end all I have been exposed to is a bunch of ideas and predictions and I have no solid ideas on those concepts. *Generating predictions and actually understanding concepts are two different things.* (Structured On-Line Interview, 12/12/96)

It is our view that highly reflective students tend to construct knowledge personally, in accordance with a reflective view of knowledge, in spite of authority-based instruction. Many (but no all) of the highly reflective students observed have strong and successful science backgrounds in the traditional system. It may be that for highly reflective students, lecture instruction is perceived not as "authority-based truth-transmission," but as "expert-based idea-explaining." The restructured course intentionally de-emphasized the "authority/expert" voice to better foster growth at the pre and quasi-reflective levels. One unintended consequence was that the lecture-free course was at times perceived by highly reflective students as unchallenging and somewhat lacking in content. It is our contention that highly reflective science students have much to gain from a collaborative, cognitively diverse class structure, but require additional instructor contact and mentoring to best meet their cognitive needs.

New Questions and Issues

Constructivist teaching, as those who have committed themselves to its implementation know, is a complicated business, perhaps more art than science. Better understanding of what takes place in a learning community requires a close examination of its social and cognitive interactions. For example, this study suggests that many students enter introductory science courses with views of science knowledge and learning which will be strongly challenged by a constructivist course. In order to better define specifics of course restructuring, it will be necessary to better understand the social and psychological dynamics which takes place when such courses are encountered by students of varying reflective judgment levels.

Recommendations for Fostering Reflective Judgment in Introductory College Science

1. *Rather than teaching students about science, engage them in authentic scientific thinking within the context of the course discipline.* Science literacy is about more than body of science content. It is about knowing how scientists think about problems and develop scientific knowledge over time.

2. *Teach less, think more.* Time must be spent on developing thinking skills. This may come at the expense of some content.

3. *Intentionally structure a complex, collaborative, social learning environment.* Too often, the only voice heard in the classroom is that of the instructor. Reflective thinking requires the decentralization of authority away from the teacher and toward the students.

4. *Guiding and modeling by a variety of peers and teachers fosters cognitive growth.* Rich social interaction requires an environment in which students not only hear and experience instruction, but each other. Students do not typically expect to engage in social complexity in college courses so therefore do not. Teachers must take a leadership role in forming learning communities, often by facilitating group work and discussion in "lecture" courses given in rooms ill-suited to the purpose.

5. *Personally mentor and lead highly reflective students.* Highly reflective students need guidance and mentoring from experts in the content area. As teachers, we are tempted to let our bright students fend for themselves cognitively, while counting on them to model skills for students functioning at other levels of reflective judgment. All students should remain active and engaged in learning, which may mean reaching out to high functioning students and creating unique situations in which they are appropriately challenged.

6. *Respect, nurture, and listen to students of all levels of reflective functioning.* Often we perceive students as "resistant," or "lazy." Validate all student views of knowledge and knowing and respect the need to express discomfort or anger.

Conclusion

The nature of classroom relationships is vital in creating an environment in which active reflective judgment is encouraged and can safely take place. The enterprise of science itself is driven by the nature and quality of the relationships among the community of scientists that most determines what is learned (Brown, Collins & Duguid, 1989). Besides facilitating reflective judgment, a collaborative learning environment is a more authentic reflection of the scientific process as practiced by scientists themselves.

> The biggest realization for me is how complicated everything is. I've always just read stats and facts in the textbook but never wondered how they came to be. I knew some smart scientist somewhere at sometime figured them out somehow, and that was good enough for me. I never thought I would do it. Now I have, with the help of a lot of other people. I've gone beyond the "reading facts" stage: I've found the facts. I not sure I ever want to do it again because it was hard!... I feel like I have kind of a bond with the solar system now. From now on when I look up at the night sky, I'll have some knowledge of what's really up there...(the facts are) a process, an exploration, and a communication with the universe. (Student Reflective Essay, 12/6/96)

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